Activities on ODS steels for Gen IV Cladding tubes

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MATISSE Workshop on cross-cutting issues in structural materials R&D for future energy systems

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www.eera-set.eu

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http://setis.ec.europa.eu/

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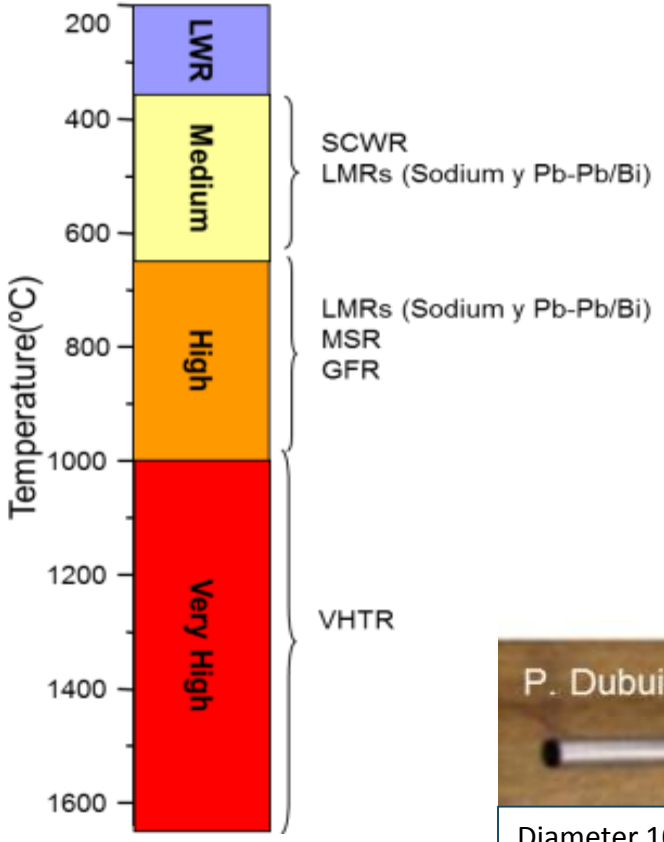
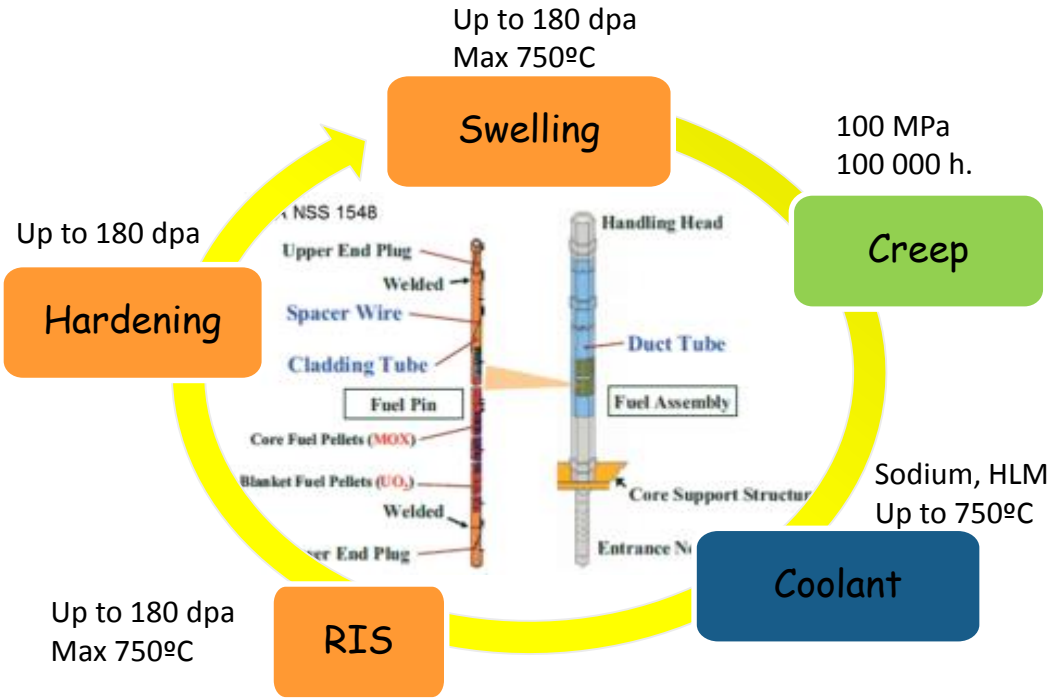
- ODS alloys
- Research projects in 7FWP
- EERA JPNM Activities
- Summary

INTRODUCTION

- Innovative high temperature resistant steels – Nuclear
- Fuel cladding tubes

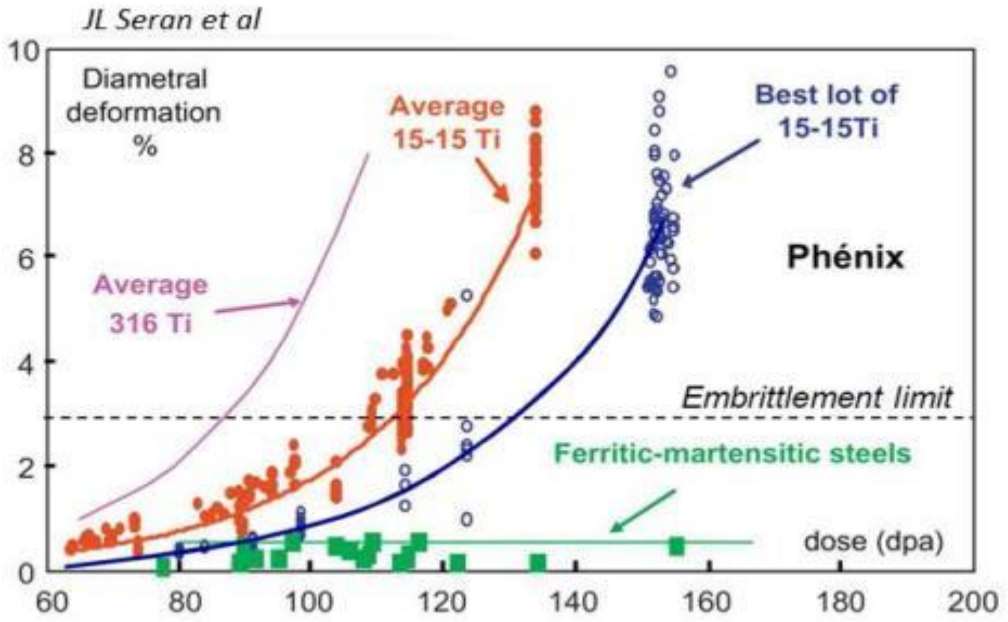




Diameter 10.73 mm, Thickness 0.500 mm, Several meters long

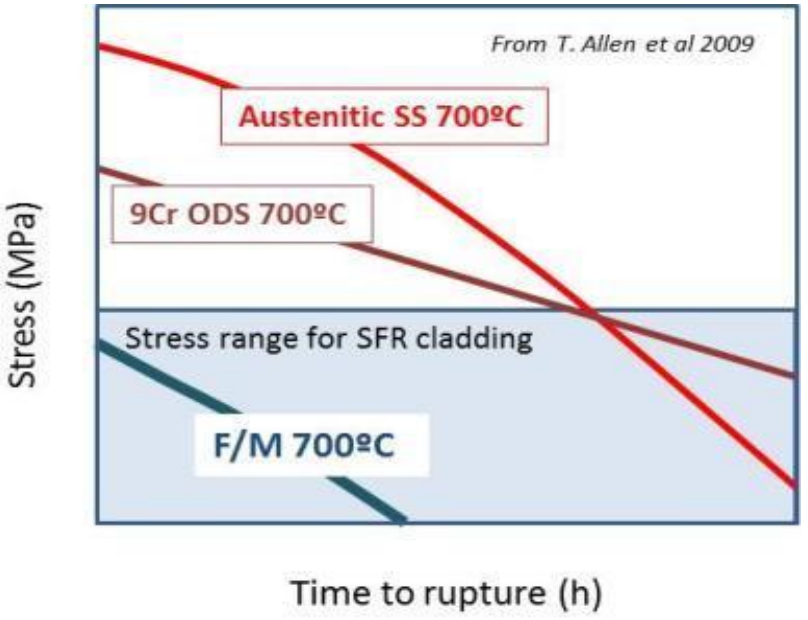
INTRODUCTION: Why F/M steels?

- Better than Austenitic stainless steels:
  - Swelling resistance - Irradiation
  - Thermal fatigue - lower thermal expansion coefficient (at least 30% lower) and higher thermal conductivity



INTRODUCTION: Improvement of F/M steels

- To solve the F/M limitations:
  - Low creep strength at high temperature
  - Low temperature radiation embrittlement



Other limitations:
- Plastic flow localization
- Cyclic softening
- Compatibility (coating)

One of the most effective ways for improving the creep properties is to **uniformly distribute fine precipitates** with long-term stability at elevated temperatures in the microstructure

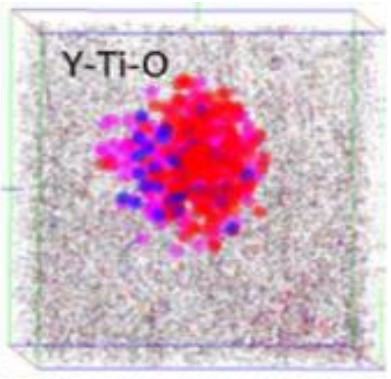
Creep strength enhanced ferritic (CSEF) steels
Dispersion of fine MX carbonitrides, Usually VN and Nb (C,N)

Oxide dispersion strengthened (ODS)
Dispersion of Y-Ti-O nanoparticles
Nano-grained microstructure

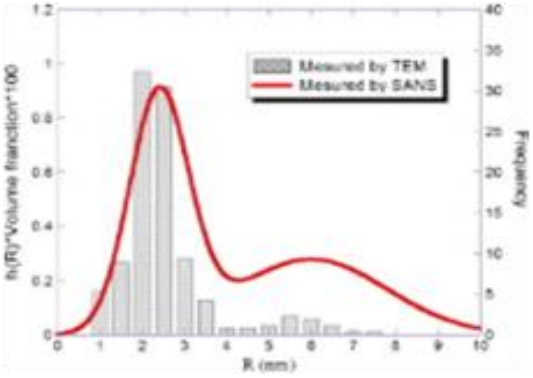
Irradiation resistance

INTRODUCTION: ODS

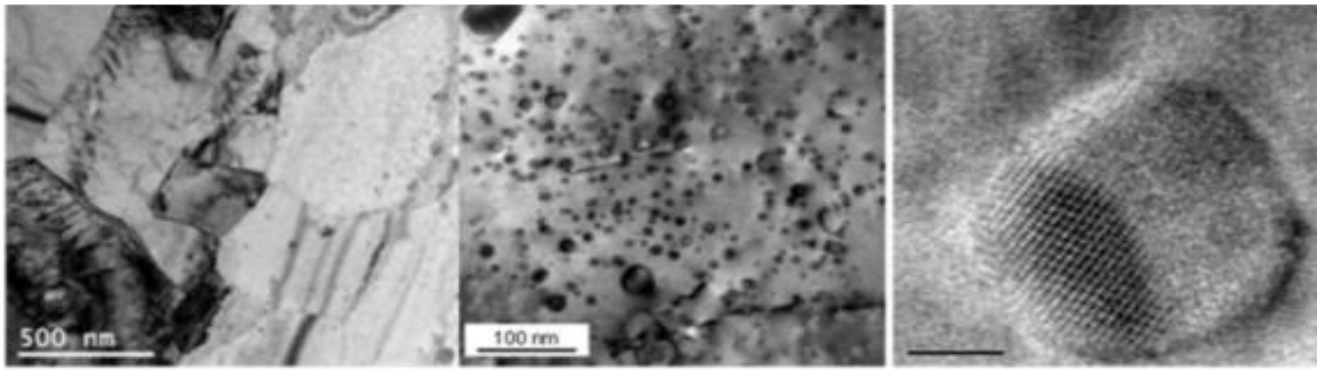
- The good qualities of ODS alloys in terms of resistance to irradiation and high performance at high temperatures result from their characteristic microstructure: homogenously distributed nano-particles in a nano-metric structure



O. Kalokhtina, 2012



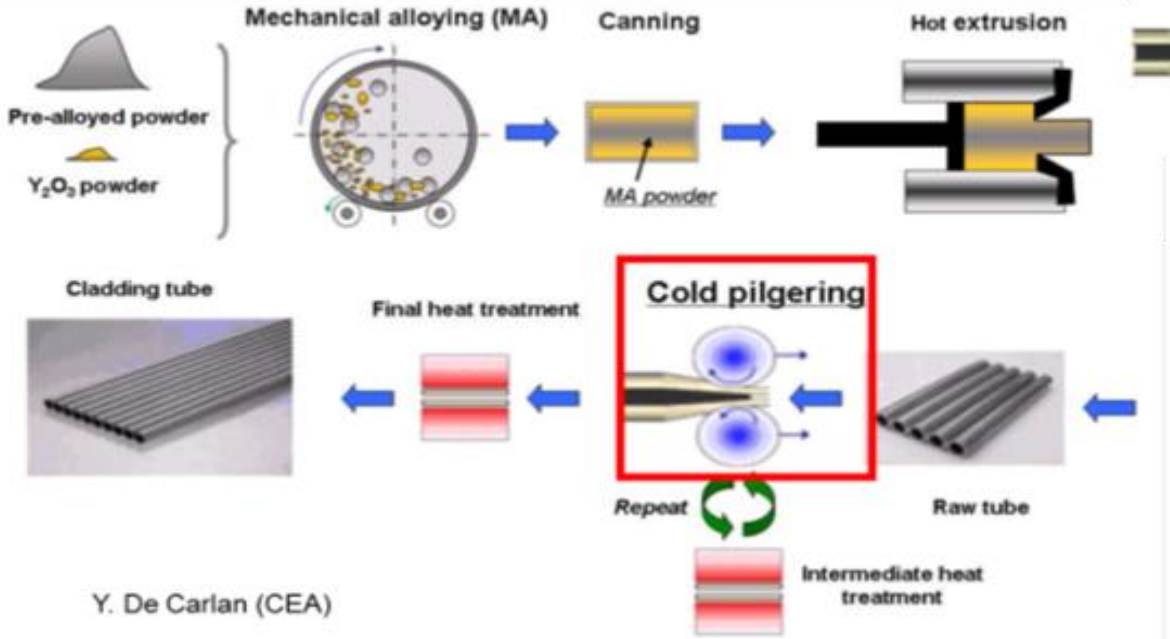
M.H Mathon (CEA)

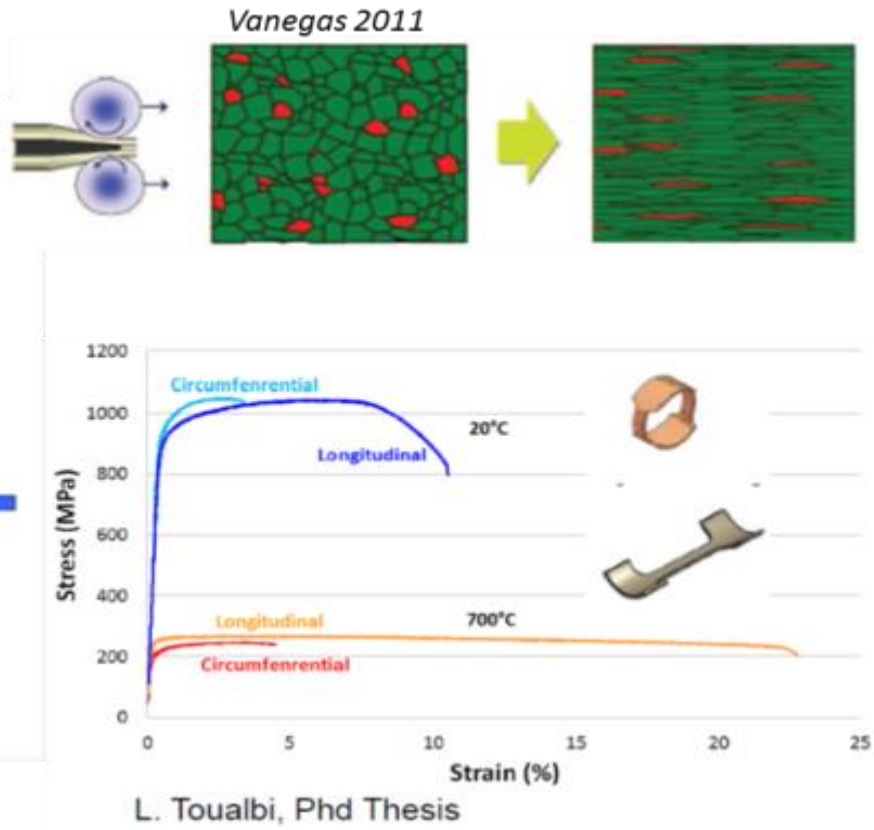


M. Hernández-Mayoral

INTRODUCTION: ODS

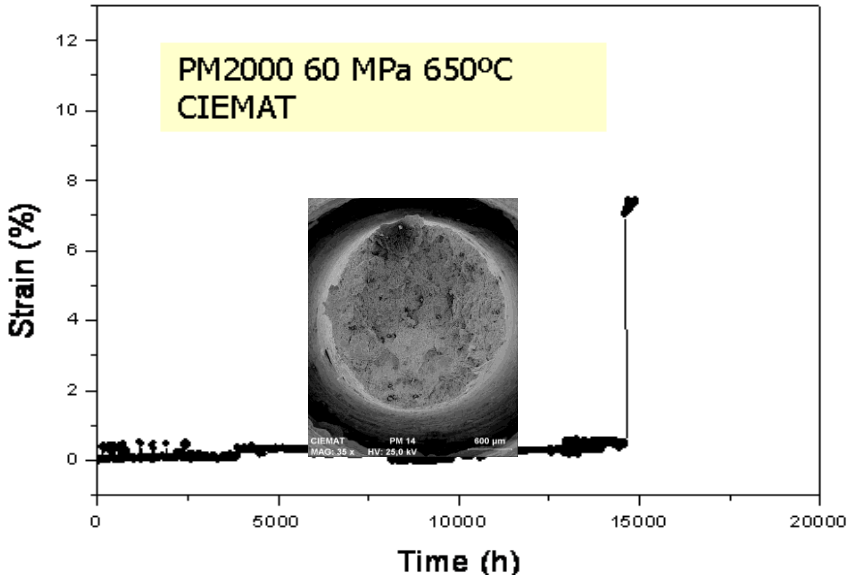
- ODS cladding tubes are fabricated by powder-metallurgy
  - Anisotropy: texture and grain morphology

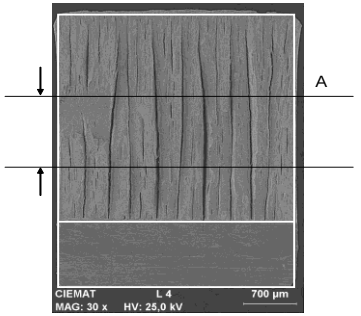




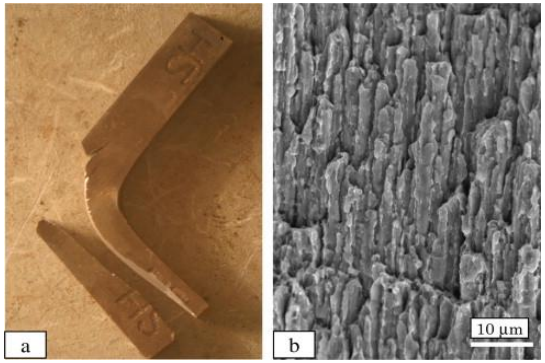
INTRODUCTION: ODS

- Main open points:
  - "Innovative "
    - First ODS patent 1974
  - Fracture behaviour, that is not so important for high temperature, but has to be understood
    - Delamination in impact and fracture toughness
    - Creep behaviour is characterized by a very low strain rate but and abrupt fracture
  - Production
    - Reproducibility between heats
    - Reduce fabrication cost (powder metallurgy or new routes)
    - Lack of industrial supplier
    - Scale to industrial fabrication
  - Fully qualify material for application as cladding
  - …





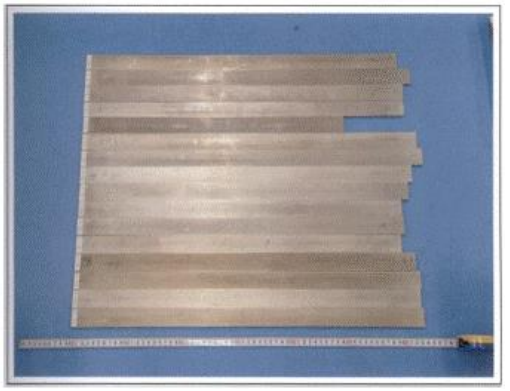
CIEMAT 12Cr ODS



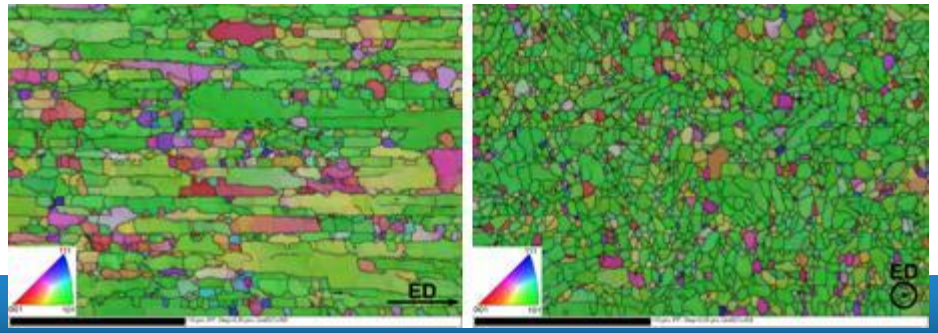
J. Henry MA957 irradiated

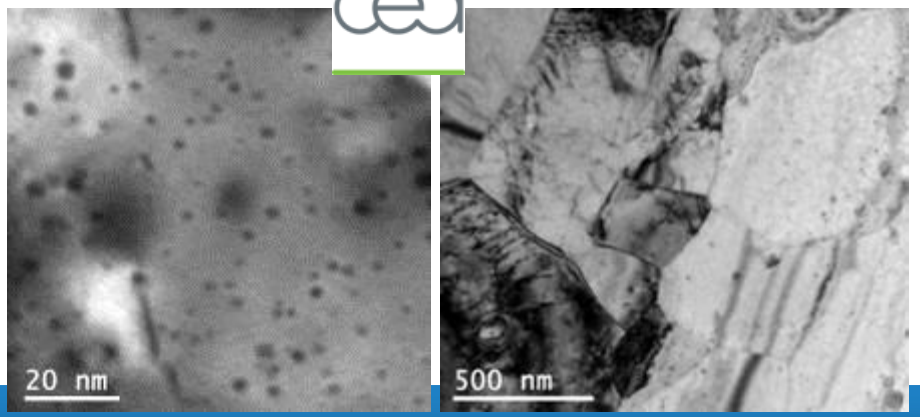
Research in EU 7FWP

- GETMAT project (2008-2013): ODS fabrication, characterization and welding
  - Extruded bar and plates
    - 45 kg 14Cr ODS bar
    - 35 kg 12Cr ODS plate and 9Cr ODS plate
  - Tensile, Charpy, Fracture toughness, LCF, Small punch, creep.
  - Explosive, FSW, EMPT and conventional TIG/EB joining techniques
  - Irradiation campaign



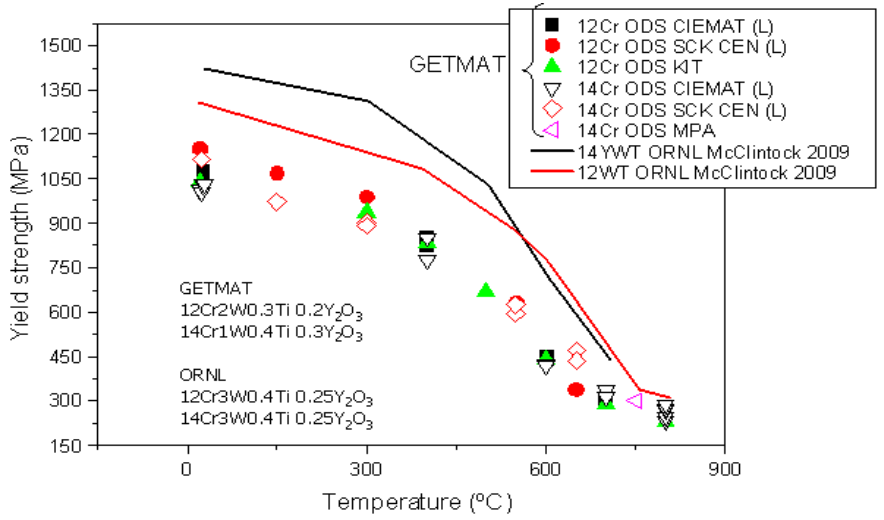
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

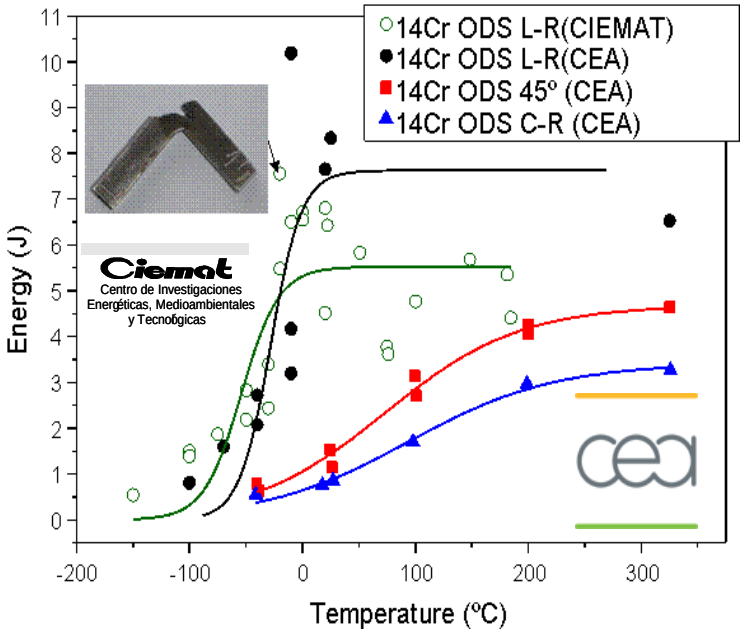


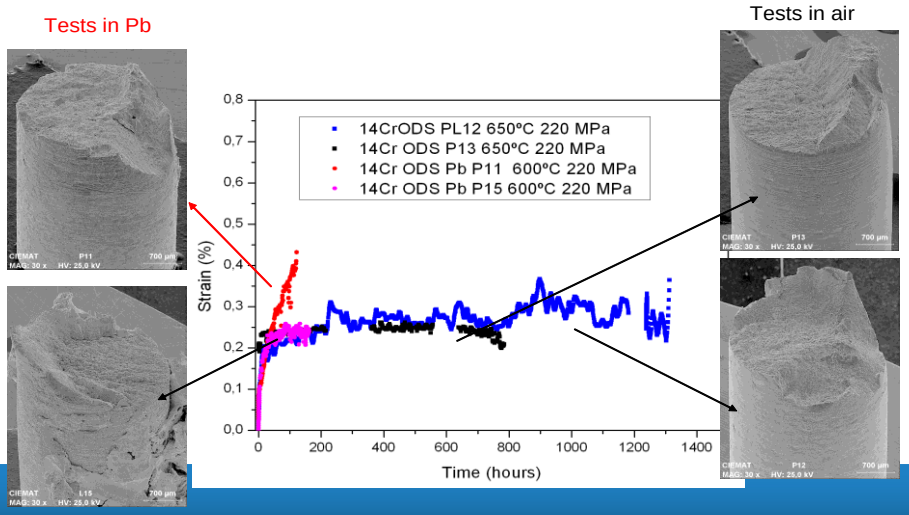


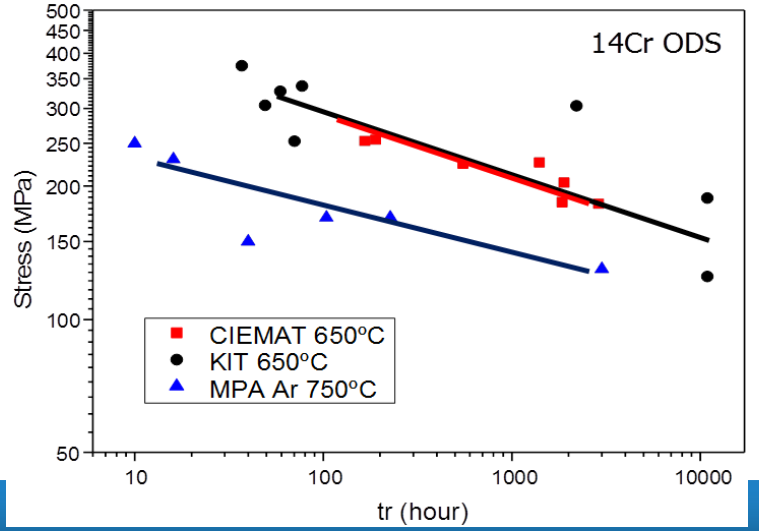
Research in EU 7FWP

GETMAT project (2008-2013)



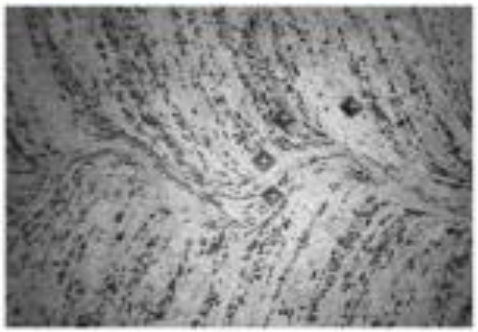




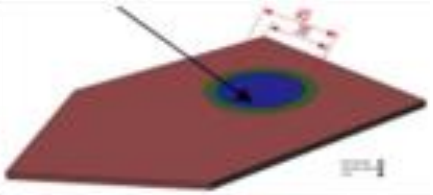


Research in EU 7FWP

GETMAT project (2008-2013)



14Cr ODS coin

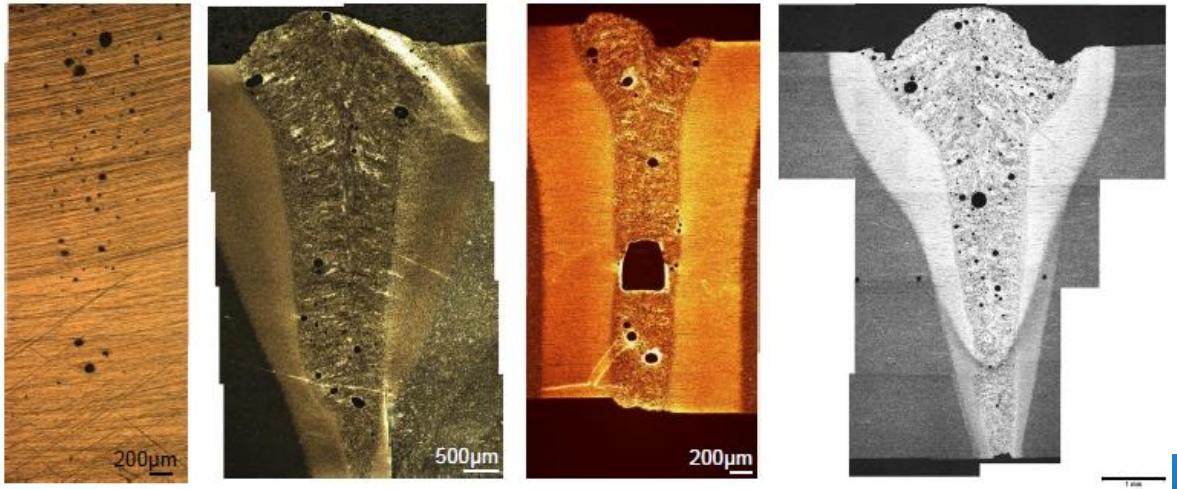


NRG

KIT
Karlsruher Institut für Technologie

Electron beam

More than 5 investigations in welding P91 with ODS P91 results no feasible output

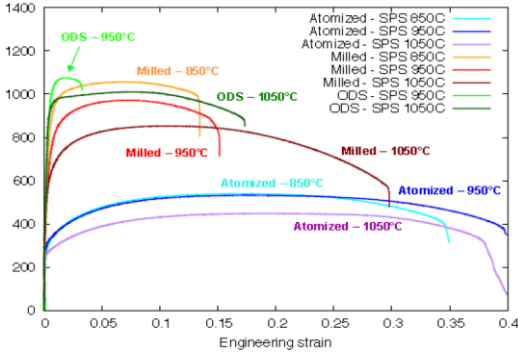


Research in EU 7FWP

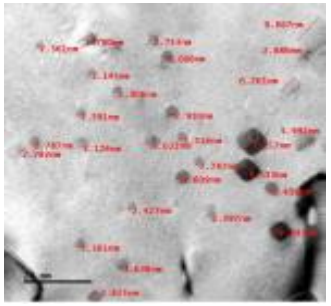
- Exploring ODS new fabrication routes: (FP7/MATTER)
  - Improvement of powder metallurgical process and optimization of final thermo-mechanical treatment
  - Conventional steel making techniques (introducing the oxide particles in the melt)
  - Spark plasma sintering techniques

SPS-HZDR

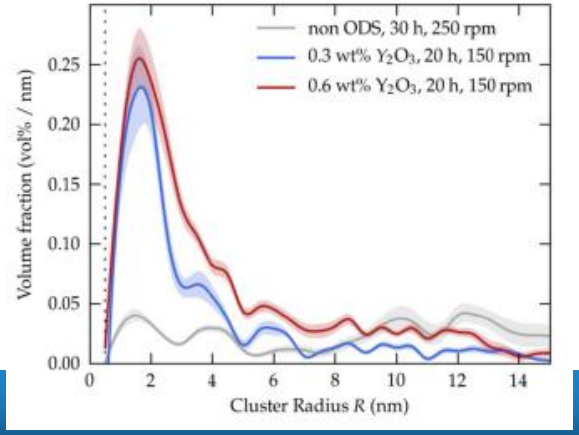
SPS - CEA

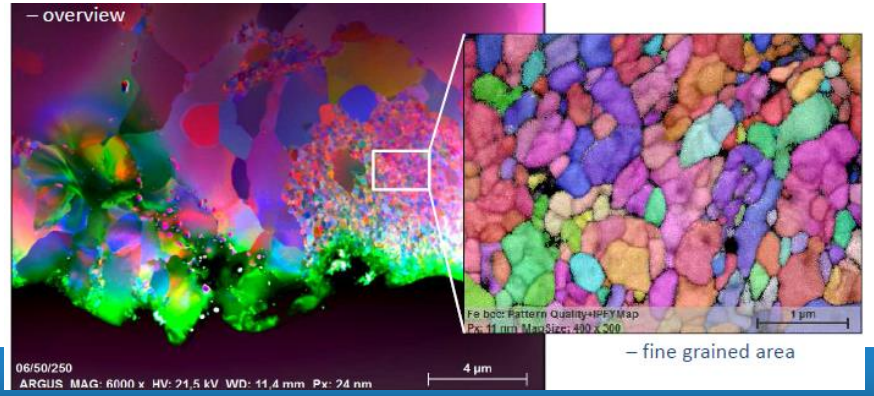


Low energy milling CSM



HZDR





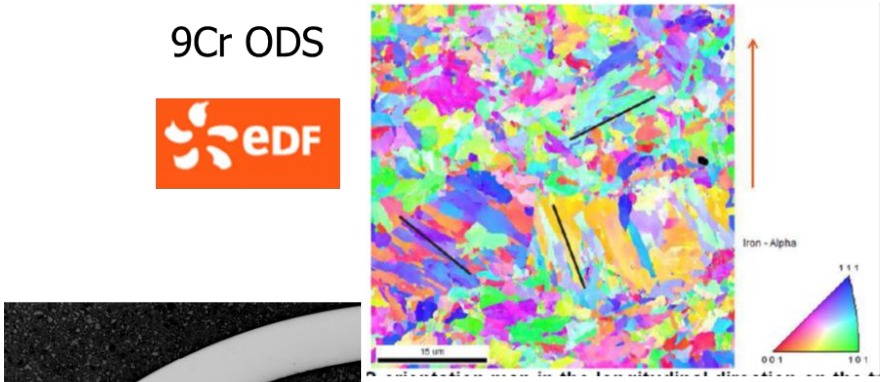
Research in EU 7FWP

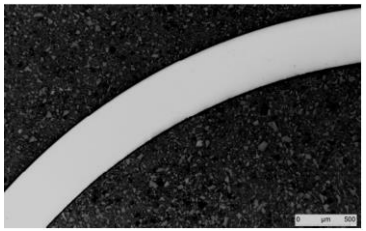
- ODS cladding tubes characterization (FP7/MATISSE)
  - Microstructural stability under high temperature and irradiation
  - Anisotropy studies (biaxial mechanical testing)
  - Screening activities under accidental scenario

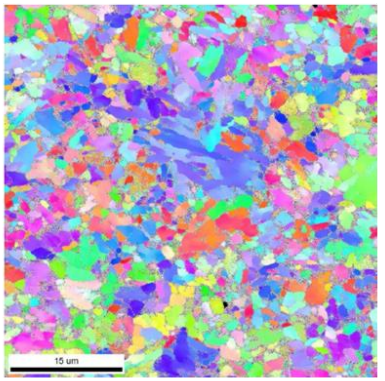
ODS cladding tube

Longitudinal

9Cr ODS

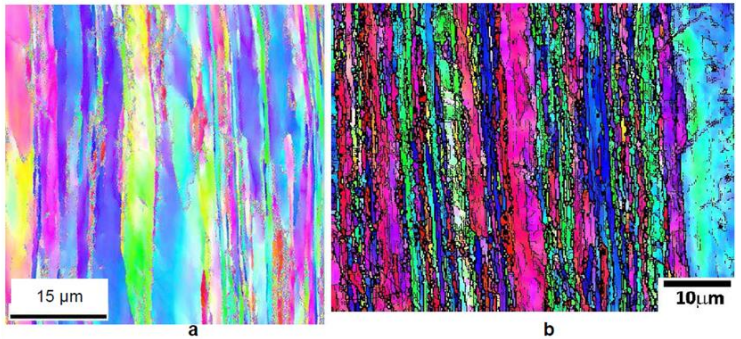


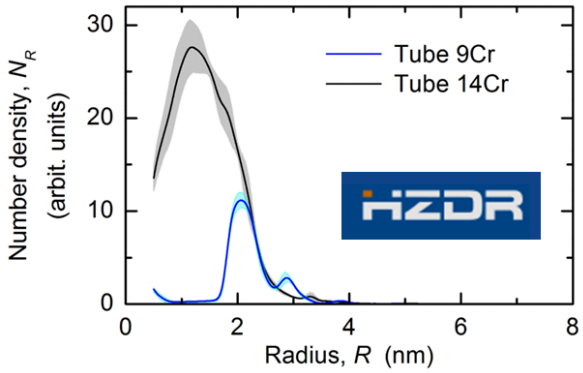




Transverse

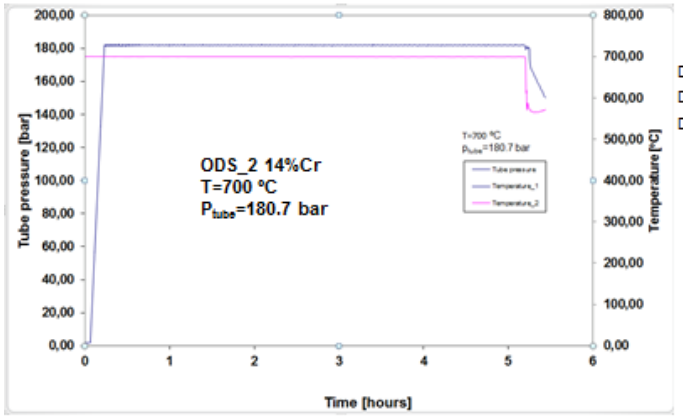
14Cr ODS Cladding tube

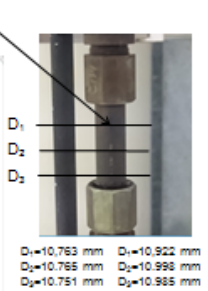




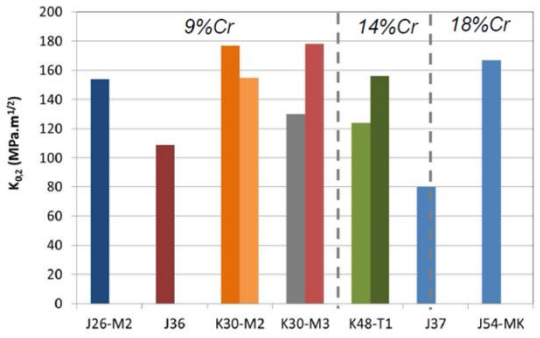
Research in EU 7FWP

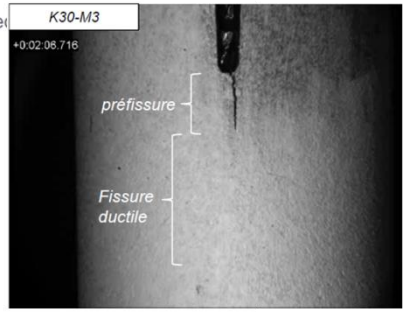
ODS cladding tubes characterization (FP7/MATISSE)



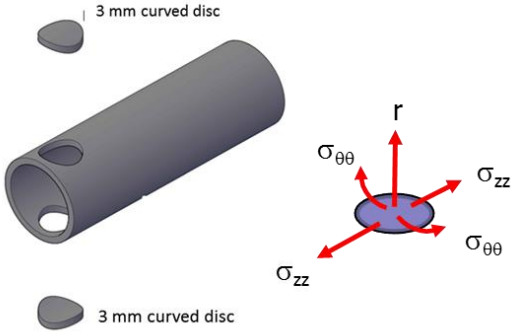


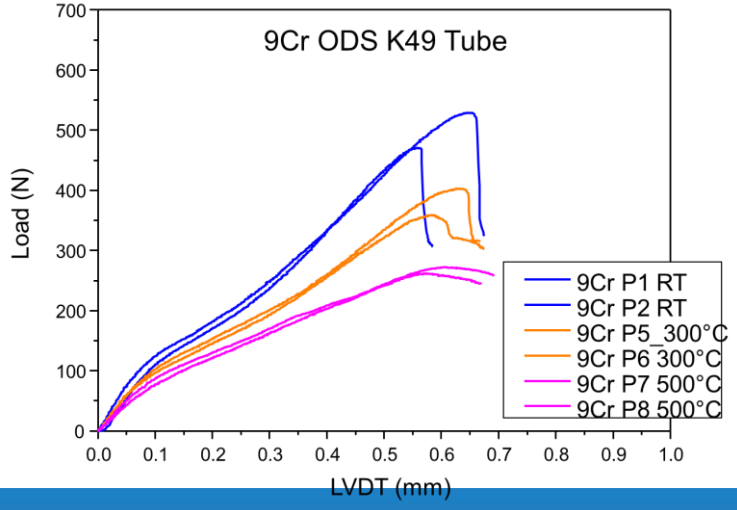
- The determination of the toughness of 4 ODS alloys was performe(K48, J37)
- Toughness ($K_{0,2}$) are between 80 et 180 MPa.m$^{1/2}$
- That is superior to a previous Ramsès criteria (20MPa.m$^{1/2}$)





ODS cladding tube





EERA JPNM SP2 Next period 2016-2020

EERA JPNM
Pilot Projects Proposal

- ODS:
  - Improvement of production routes
  - Deep analysis of deformation mechanisms (brittle and high temperature) and fracture
  - Stability of the microstructure under long term exposure at high temperature and irradiation, including recrystallization (abnormal grain growth) studies

AFROS

PROMETEUS

FRACTO (SP1-SP2)

- Creep-Strength-Enhanced F/M steel:
  - Optimization of microstructure and treatments to balance the improvement of creep and minimal loss of toughness
  - Microstructure stability under deformation, high temperature and irradiation
  - Compatibility

CREMAR

- Alumina forming Alloys

ALCORE (SP1-SP2)

NMP FUSION Research in SP2

MAtISSE (2014-2017)
(~450 k€ / 50% + 450 k€ in-kind)
Clad. tube characterisation

MATISSE
Materials' Innovations for Safe and Sustainable nuclear

EERA
European Energy Research Alliance
JP Nuclear Materials

EERA JPNM Pilot Projects (2016-2020)

- FRACTO: Fracture toughness (SP1_SP2)
- ALCORE: Alumina forming steels (SP1_SP2)
- CREMAR: Creep Strength Enhanced Ferritic (CSEF)
- AFROS: Alternative ODS production routes
- PROMETEUS: Micro-plasticity

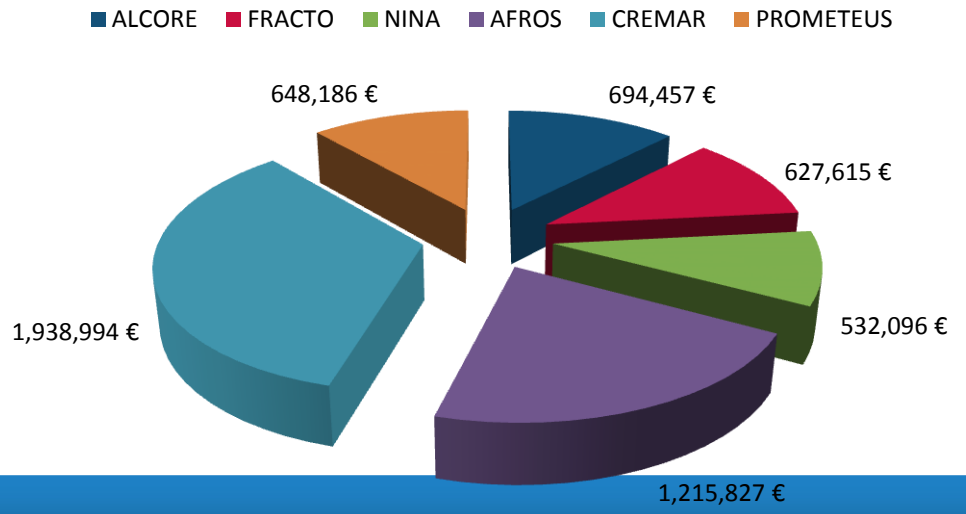
MATTER
SEVENTH FRAMEWORK PROGRAMME

MATTER (2010-2014) (~0.5 M€ / 50%)
Optim. fabrication route

FP7 PROJECT GETMAT

GETMAT (2008-2013) (~1.5 M€ / 50%)
ODS fabrication & characterisation

EERA PPs (2016-2020) (~5.6 M€)



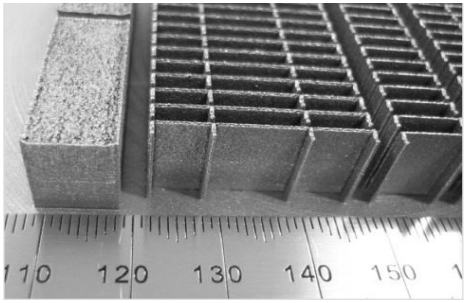
Synergies with other Energies

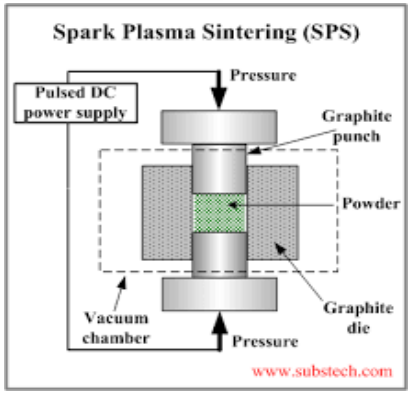
- Commonalities
  - Material production
    - ODS
      - Powder Metallurgy
      - Conventional/new techniques
    - Enhanced creep F/M
      - Supported by modelling
  - Material characterization:
    - Thin-walled tubes
    - Biaxial testing

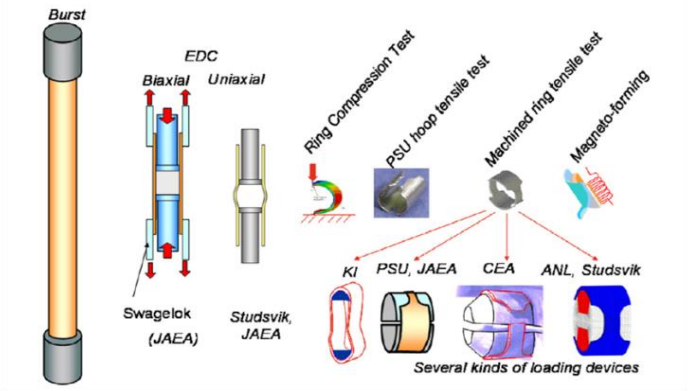
EERA JPNM Pilot Projects – **OPEN FOR COLLABORATIONS**

- FRACTO: Fracture toughness
- CREMA: Creep Strength Enhanced Ferritic (CSEF)
- AFROS: Alternative ODS production routes

PM2000 Slective Laser melting
Liverpool Univ.







A schematic depicting hoop tensile testing techniques recently used to assess the mechanical response of high burnup cladding J. Desquines (IRSN)

Thank you for your attention